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ANALYSIS OF AN ELECTRO-OPTICAL SATELLITE OBSERVATION.(U)

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY

ANALYSIS OF AN ELECTRO-OPTICAL SATELLITE OBSERVATION

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Group 94

PROJECT REPORT ETS-59

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ABSTRACT

A satellite has been observed through an optical telescope with a CCD camera, the electrical signal stored, and later analyzed with the aid of a digital computer. The unresolved satellite image is contained in 3 to 7 picture elements in fifty contiguous data frames. This allows a better understanding of the physical characteristics of the satellite image as viewed through the atmosphere by an electro-optical detector.

This paper describes the data processing programs used to analyze the data, the analysis results, and implications for signal processing design.

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I. INTRODUCTION

A CCD camera has the potential of improving the performance of satellite detection systems by means of higher quantum efficiency, smaller pixel size, and more pixels on a focal plane than EBSICON cameras. An efficient satellite detection processor should be designed to exploit the signal characteristics of the camera it uses as an electro-optical detector. Selected portions of a digital satellite detection processor (IMC Signal Processor) and CCD camera are being developed for the GEODSS advanced technology program. The output of a CCD camera, when observing a satellite, has been digitized, and then analyzed with the aid of a computer. This allowed a detailed study of the electrical signal that the processor would have to use prior to designing the processor.

Satellite ATS-6 was observed with the 31" main GEODSS ETS telescope at the White Sands Missile Range. The CCD camera was at the prime focus and was operated in the stare mode with an 0.1 second integration time. The ETS photometer measured the satellite's brightness as 10.5 Mv. The camera video was digitized to 12 bit resolution, sent to the MODCOMP computer at the ETS and stored on magnetic tape. This tape was brought back to Lexington and placed on the MODCOMP computer here. The tape was read by the MODCOMP and the data transmitted to the HP 9845 graphics computer and stored there. The HP computer was used for all the data analysis.

The satellite observation is contained in fifty contiguous frames. Each frame contains an array of 32 x 32 picture elements (pixels). The integration time for each frame was 0.1 second. Each pixel has the equivalent field-of-view of $2''.7 \times 2''.7$.

II. DATA PROCESSING

The frames of data were read from the digital tape by the MODCOMP computer and transmitted, on an RS-232C interface[1], to the HP computer. Using this interface the HP computer[2] was operated to look like a standard terminal to the MODCOMP. The major task of this interface was to write an HP terminal emulator program. This program has to read the data from the interface, store the data, and respond to the MODCOMP with standard terminal handshake commands. The program, "MOD-HP", listed in Appendix A did this at 9600 baud.

To operate at this high a rate, each data word was read as a character string. The character strings were stored on HP tape cassettes as the data word was being read. The 1024 character strings from each frame were separated by markers. Once all fifty frames of the character strings were stored on tape, the HP computer was disconnected from the MODCOMP, and was operated independently from then on.

Two tape cassettes were required to store all the character strings. All the character strings were then read off the tapes and stored on one floppy disc using the "COPY" program listed in Appendix A. The character strings cannot be used in programs, but must be converted to the numbers they represent. The program "READ", Appendix A, read the character strings off the disc, converted the character strings to numbers and stored

1. Hewlett Packard, "Serial I/O Interface-98036A," 1977.
2. Hewlett Packard, "I/O ROM Programming System 45B," 1979.

these on tape. The "COPY" program was again used to transfer data from tape to disc.

To insure that the data stored on the disc was accurate, a print-out of the data stored on the MODCOMP tapes was compared to the data stored on the HP disc. The data was identical in frame-to-frame and entry-to-entry comparisons. The first data entry in each frame of both the MODCOMP and HP data was the same, but was not a valid data value. To avoid problems in data processing the value of the first data entry, in each frame, was set to the mean of the data of each frame and is then called a valid data frame.

Now the data is ready to be analyzed. The first data analysis program is "MAXAMP" listed in Appendix B. "MAXAMP" finds the maximum amplitude in each frame and prints the frame number, amplitude, and array position. A sample of "MAXAMP" output is shown in Figure 1. The frame number, e.g. T11V01:F stands for CCD-DIGITIZER test #11 (T11), valid data frame (V), frame number (01), and stored on floppy disc (F). The pixel array position is numbered from 1 to 1024 in each data frame.

The next data analysis program listed in Appendix B is "FREDIS" which plots the frequency distribution of amplitudes for each frame. Figure 2 contains plots from two of the fifty frames. The amplitude scale adjusts for each frame depending on the maximum amplitude. The occurrence scale also adjusts

FRAME			POSITION
T11V10:F	MAXIMUM AMPLITUDE	185	276
T11V11:F	MAXIMUM AMPLITUDE	182	276
T11V12:F	MAXIMUM AMPLITUDE	163	276
T11V13:F	MAXIMUM AMPLITUDE	159	277
T11V14:F	MAXIMUM AMPLITUDE	224	277
T11V15:F	MAXIMUM AMPLITUDE	176	277
T11V16:F	MAXIMUM AMPLITUDE	208	277
T11V17:F	MAXIMUM AMPLITUDE	173	277
T11V18:F	MAXIMUM AMPLITUDE	147	277
T11V19:F	MAXIMUM AMPLITUDE	180	277
T11V20:F	MAXIMUM AMPLITUDE	172	276
T11V21:F	MAXIMUM AMPLITUDE	143	276
T11V22:F	MAXIMUM AMPLITUDE	144	276
T11V23:F	MAXIMUM AMPLITUDE	143	276
T11V24:F	MAXIMUM AMPLITUDE	175	276
T11V25:F	MAXIMUM AMPLITUDE	184	276

Fig. 1. "MAXAMP" sample output.

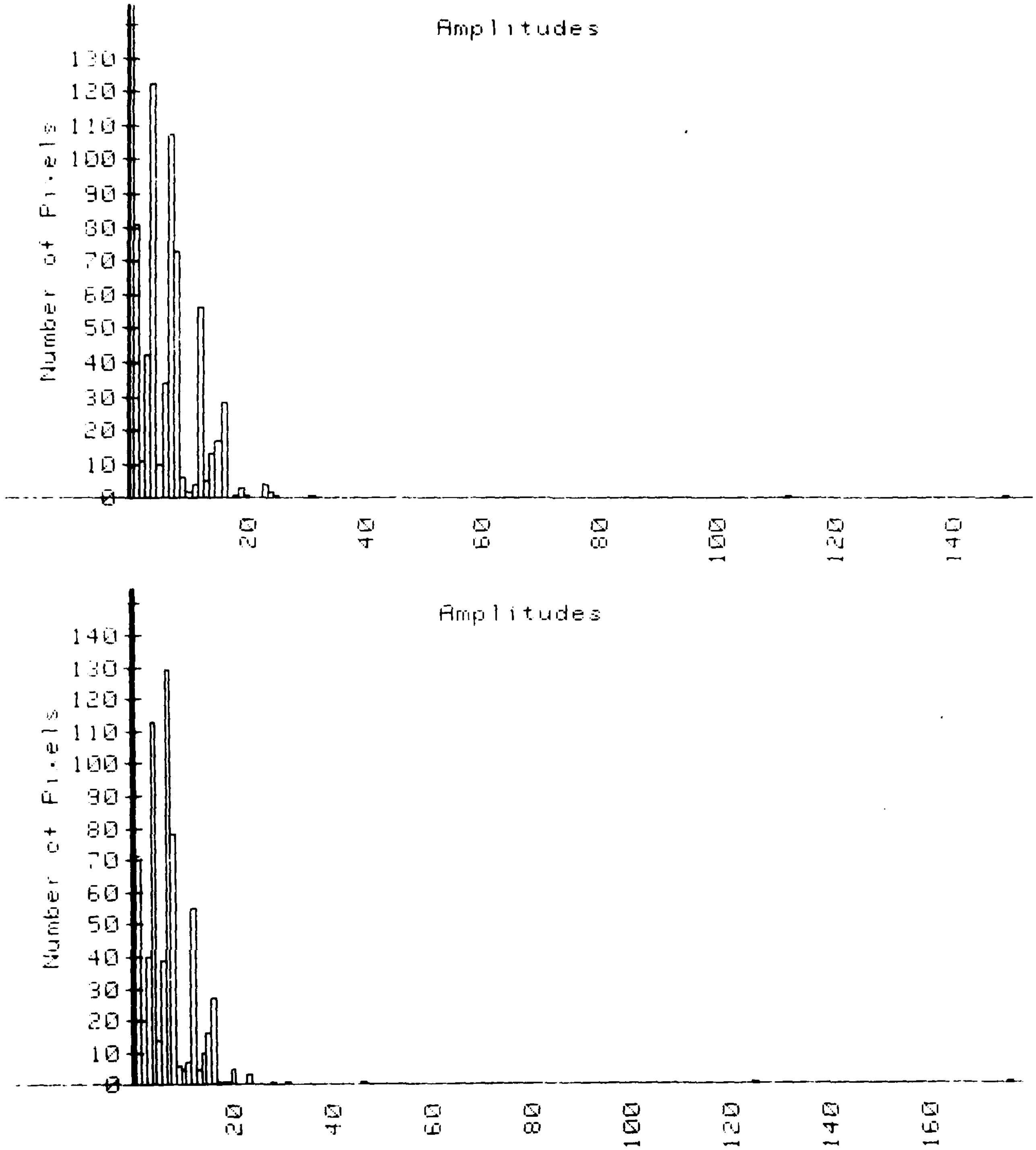

Fig. 2. "FREDIS" output for two frames.

depending on the number of pixels, excluding the zero amplitude, for which there are from 350-400 pixels in each frame.

The program "PEAKS" examines a frame of data and prints out the location and amplitude of any pixel whose amplitude is above a selected level. Figure 3 is a sample of "PEAKS" output. A program listing of "PEAKS" is in Appendix B. The frame number is given and the selected level (e.g. 19). The row, column, array position (as in "MAXAMP" output), and corresponding amplitude are listed.

Program "DATAST", Appendix B, prints out the amplitude values of any frame by row and column. An asterisk is placed next to amplitudes above a selected amplitude. The output is displayed on the CRT or printed on the line printer. A sample of output from frame #11 is shown in Figure 4. The top line of each pair is array elements 1 to 16 and the second line is array elements 17 to 32. In this frame the satellite pixels have amplitudes of 182, 112, 32, and 40. An isolated pixel of noise with amplitude 32 is one array line above this.

The "FRAME" program (Appendix B) allows a 13 x 11 pixel array around the satellite image of any frame to be displayed. After the array of pixels is displayed, the amplitudes are plotted first in column and then in row. Figure 5 is a print-out of the array of pixels around the satellite image from

T11V03:F PEAKS ABOVE 19

ROW	COLUMN	POSITION	AMPLITUDE
3	10	291	32
20	9	276	56
20	10	308	28
21	9	277	158
21	10	309	35
21	11	341	47
22	9	278	23
22	10	310	20
23	9	279	28

T11V08:F PEAKS ABOVE 19

ROW	COLUMN	POSITION	AMPLITUDE
2	6	162	20
3	8	227	23
4	27	836	23
10	3	74	23
16	10	304	23
20	9	276	112
20	10	308	24
21	8	245	25
21	9	277	149
21	10	309	31
25	13	409	24

T11V22:F PEAKS ABOVE 19

ROW	COLUMN	POSITION	AMPLITUDE
2	7	194	33
5	23	709	23
7	3	71	20
7	7	199	22
9	30	937	20
13	22	685	23
15	4	111	20
16	11	336	20
20	8	244	24
20	9	276	144
21	9	277	125
21	10	309	32
22	11	342	24
23	11	343	20
31	14	447	24

Fig. 3. "PEAKS" sample output.

0	12	7	1	0	1	16	1	0	1	14	1	3	7	7	0
0	0	1	4	0	0	8	14	1	5	1	6	7	0	0	3
4	0	0	15	0	0	12	7	0	14	1	0	4	4	0	0
7	0	0	0	7	8	7	0	14	0	0	0	6	12	0	0
4	0	6	0	0	1	16	0	0	7	12	7	8	0	14	6
0	0	1	6	7	0	1	18	0	3	0	8	8	0	4	1
0	0	0	0	8	6	4	0	7	8	0	1	3	8	1	0
3	7	0	7	0	7	6	0	7	4	12	0	6	4	0	0
0	0	1	3	0	3	4	1	0	0	0	4	4	0	0	9
1	0	0	3	7	1	7	0	0	7	3	4	0	0	7	0
0	4	0	4	4	0	0	4	5	16	0	3	14	7	0	0
0	7	0	0	0	0	2	7	0	8	7	1	0	7	7	0
0	12	4	0	7	16	16	0	8	0	12	1	0	0	0	4
4	0	1	4	8	0	0	12	1	6	1	6	5	0	0	0
4	7	9	0	0	0	12	0	1	0	15	6	0	14	4	7
0	0	0	12	13	0	0	7	12	0	12	4	1	1	0	14
14	12	0	32*	0	0	16	6	0	0	11	1	8	0	0	7
1	0	0	0	7	0	0	16	4	4	0	7	4	15	0	0
0	0	1	8	7	8	1	15	182*	32*	15	12	1	7	7	0
0	0	14	8	8	8	12	15	12	0	7	12	1	0	4	0
7	0	0	14	4	0	0	19	112*	40*	7	14	0	12	12	12
4	1	16	14	3	8	16	4	0	0	0	4	4	12	0	0
0	12	0	0	16	14	1	0	17	18	12	3	7	15	7	0
0	4	0	0	0	12	7	0	12	16	2	0	1	0	0	0
4	0	0	7	4	0	7	8	7	1	0	4	7	4	0	0
1	14	3	4	0	7	16	0	4	0	12	7	0	0	12	0
0	2	14	12	4	6	15	0	0	4	7	0	7	8	4	1
0	8	6	13	1	1	2	4	7	0	1	7	0	7	0	0

Fig. 4. "DATAST" sample output.

0	4	0	0	4	12	7	4	0	0	7
0	7	0	1	24	7	1	8	12	13	0
1	7	7	0	0	14	16	7	15	1	7
1	7	15	13	0	28	24	24	12	0	8
6	4	0	0	7	163	95	4	0	16	7
3	16	4	5	7	36	31	4	12	0	3
8	7	8	12	11	2	0	0	7	1	4
0	4	1	1	0	12	3	7	0	0	12
4	8	12	0	0	15	4	7	7	7	0
23	7	9	0	0	2	4	0	0	0	6
8	7	0	0	3	0	0	0	16	4	1
0	4	0	0	7	0	0	0	7	0	0
4	4	0	0	4	0	7	4	0	0	0

Fig. 5. "FRAME" sample output.

frame #12. Figure 6 is a plot of the amplitude in the sixth column of Figure 5. The dashed line is a level at an amplitude of 19. Figure 7 is a plot of amplitudes in the fifth row of Figure 5. The dashed line is also at an amplitude of 19.

Appendix C contains the pixels (5 x 6) surrounding the satellite image for frames 1 through 12. These were obtained using a modified version of program "FRAME".

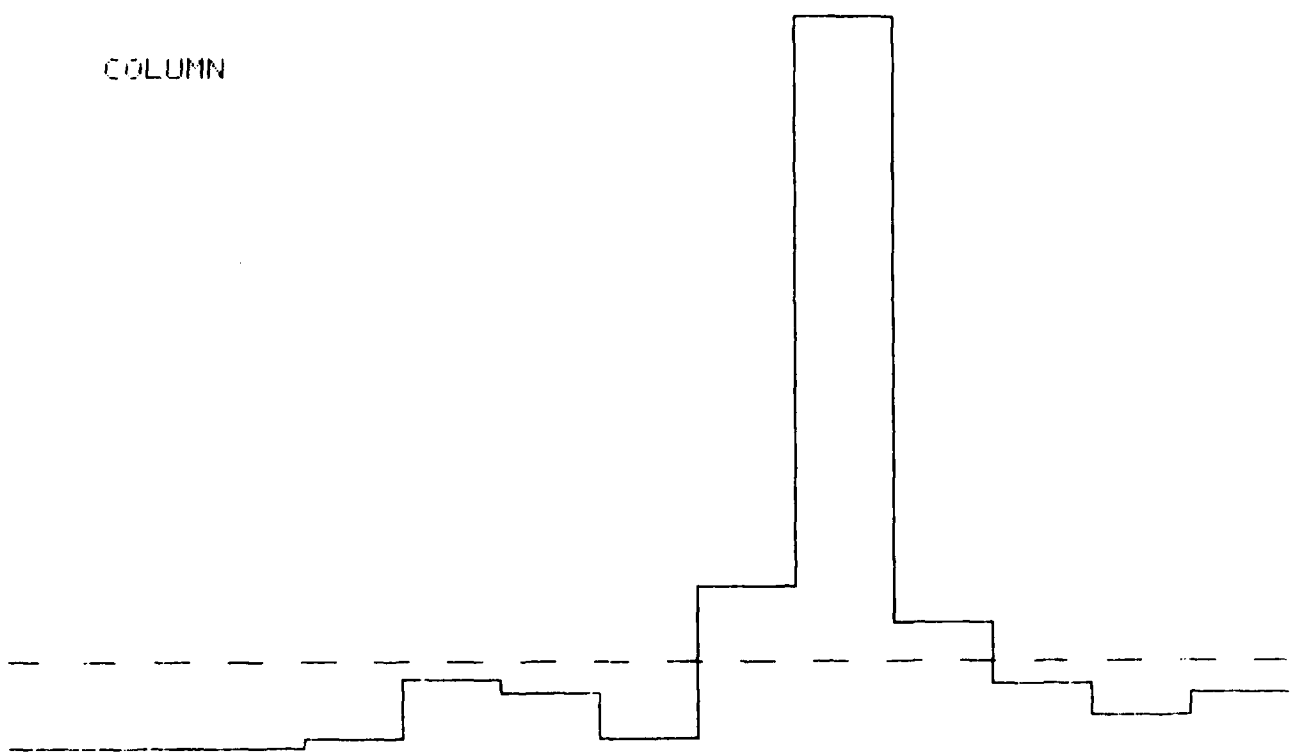

Fig. 6. "FRAME" output, column plot.

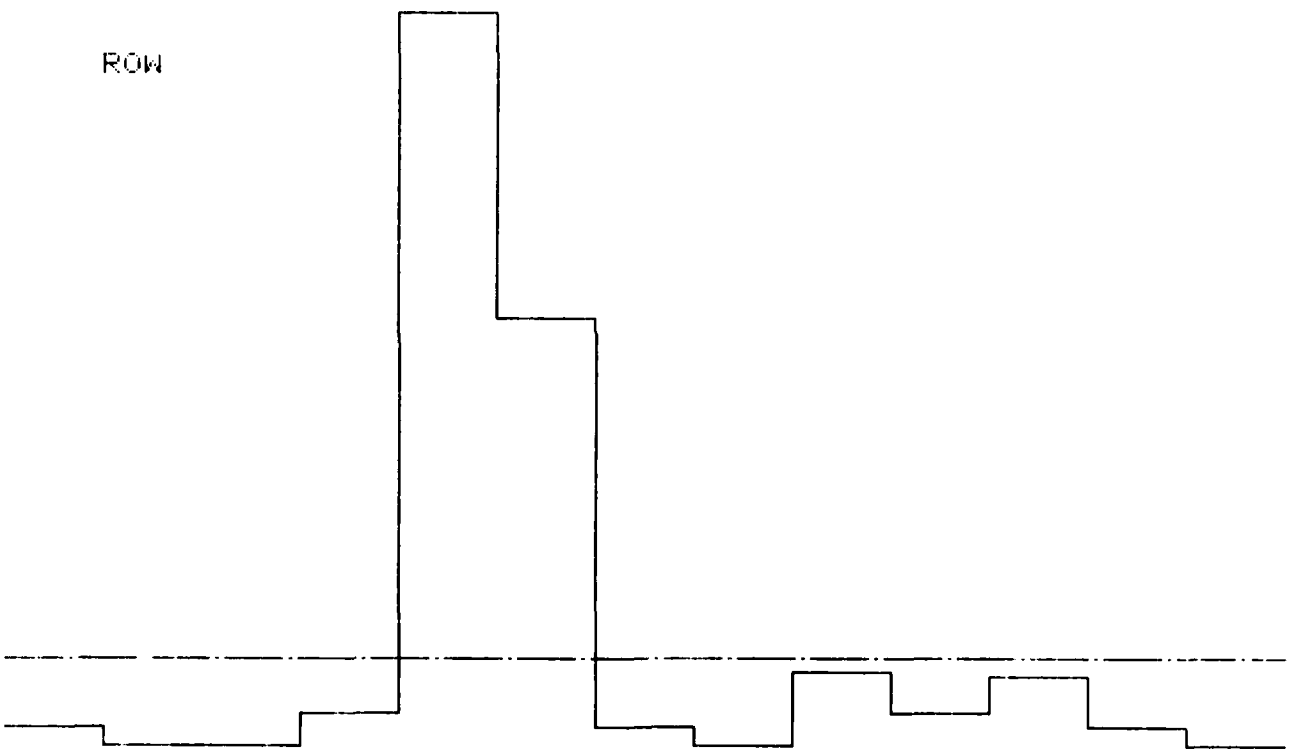

Fig. 7. "FRAME" output, row plot.

III. ANALYSIS OF DATA

Analysis of the output of the "MAXAMP" program indicates that the highest amplitude of the satellite image moves between two adjacent pixels. Over the fifty frames, the highest amplitude switches 15 times between the two pixels, spends an equal amount of time in each and there is no periodicity to the switches. The range of highest amplitudes is 127 to 224 with a mean of 165. The mean of highest amplitude in one pixel is 162, while the other pixel's highest amplitude mean is 169.

Examining the output of "FREDIS" shows that in all frames most of the pixels have amplitudes from 0 to 17. The mean of the amplitudes from each of fifty frames ranges from 4.4 to 4.9. This is strongly due to the large number of pixels (350 to 400) in each frame with amplitudes of zero. The distributions of all fifty frames are similar. All frames have less than 20 pixels above an amplitude of 19.

The output of "PEAKS" shows that in every frame the pixels with amplitudes greater than 28 are either those of the satellite image or of isolated pixels. There are 532 pixels that have amplitudes greater than 19 in the fifty frames. Most of these pixels are either those of the satellite image or isolated pixels. However, 12 of the pixels in 10 of the fifty frames have an adjacent pixel greater than 19. In half of these cases the adjacent pixels are vertically related and in half horizontally.

The pixels with amplitudes greater than 39 are all those of the satellite image.

The output of "DATAST" shows that the noise is uncorrelated from pixel to pixel and from line to line. Eight-four percent of the pixels with an amplitude greater than 8 have no adjacent pixel with amplitude greater than 8. Ninety-three percent of the pixels with amplitude greater than 12 have no adjacent pixel with amplitude greater than 12.

The output of "FRAME" gives information primarily about the pixels associated with the satellite image. Table 1 is a summary of the distribution of satellite image pixels by frames. The distribution of energy from the satellite image is very dynamic. The distribution changes significantly in periods of 0.1 sec to 0.3 sec. In 61.5% of the frames the energy distribution doesn't fit a circular Gaussian function.

TABLE 1

NUMBER OF SATELLITE PIXELS FOR FIFTY FRAMES

Amplitude Higher Than	Satellite Pixels	Number of Frames
24	3	10
	4	25
	5	12
	6	2
	7	1
29	2	1
	3	19
	4	28
	5	2
32	2	17
	3	31
	4	2
34	2	21
	3	27
	4	2
39	2	29
	3	21
49	1	3
	2	44
	3	3
99	1	16
	2	34

IV. SIGNAL PROCESSING CONSIDERATIONS

After reviewing the analysis results, it is apparent that the satellite image is not stable over time periods as short as 0.2 sec. The instability of the image could result from three primary sources: satellite motion, telescope jitter, and atmospheric seeing. During the time of data collection, the ATS-6 satellite was a three-axis stabilized geosynchronous satellite. Its reflected light vs. time had been measured by several observers at the ETS and was found to be steady throughout the night, as would be expected from this type of satellite. Therefore satellite motion didn't account for the image instability observed in the data. The fifty frames of data were carefully scrutinized to detect any indication of telescope jitter. Telescope jitter would be detected in the data, if the pixels which contain the satellite image shifted together in the same direction. There is no observable correlation between the maximum amplitude pixel shift direction and the other satellite image pixels' shift direction. Calculating the centroid of the satellite pixels shows that the centroid movement is in random directions rather than in one or two orthogonal directions that would characterize telescope jitter. Atmospheric seeing is therefore the leading candidate as the source of the image instability. Although few measurements of atmospheric seeing with time constants as short as 0.1-0.2 sec, and with two-dimensional spatial resolution as fine as 2"7 have been reported, one reference[3] does report the characteristic image fluctuation seen in this data as atmospheric seeing. Many other reports on atmospheric seeing describe image fluctuation similar to that observed in this data. Atmospheric seeing will affect stellar images in the same fashion. A signal processing system that removes stars by comparing a star field at one time with the same star field at a time 0.2 sec later or longer, must incorporate a technique to reduce false alarms due to the star image instability. These false alarms are located adjacent to star images, and a guard band around each star that inhibits detections would remove these false alarms.

Although the resolution of the telescope is $1''.0$ or smaller and the pixel resolution is $2''.74$, the satellite image is in 3 to 7 pixels. Most of the energy is in 2 to 3 pixels, however in 74% of the frames the energy is in 4 to 5 pixels. In more than half the frames the distribution of satellite energy doesn't fit into a circular function. There is little correlation from frame-to-frame of the spatial distribution of satellite energy. This requires that predictions of satellite SNR and system detection performance be modified to incorporate these physical realities.

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3. MIKESELL, A.H. et al, "The Scintillation of Starlight", JOSA, 41, 689-695, 1951.

The star and satellite images are in several adjacent pixels (at a 2".74 pixel size), while the noise is only one pixel long. This is an excellent discriminant between the satellite and high amplitude noise that competes with the satellite signal. If a threshold level of 28 was used with the pixels in the fifty frames, the threshold crossings would be due to the satellite (adjacent threshold crossings) or to the noise (isolated threshold crossings). The isolated threshold crossings could then be removed and only the satellite threshold crossings would remain. As the threshold is lowered, noise threshold crossings will be more frequent and false alarms due to noise will start to reappear. At a threshold of 28, 100% of the noise false alarms are removed; at a threshold of 12, 93%; and at a threshold of 8, 84%. The remaining false alarms due to noise can be removed by additional processing (streak, slope, velocity, etc.).

V. CONCLUSIONS

The analysis of a satellite image as seen by a CCD camera mounted on the 31" prime focus at the ETS has been accomplished. The complexity of the image as a function of spatial distribution and time can be clearly seen. The seeing effects were worse than what had previously been expected at the ETS. The utility of having a digitized, stored signal from a sensor before designing a signal processor that uses that particular sensor, is obvious.

The pixel size of a camera is important to the detection system; as too small a pixel will cause the satellite energy to be spread over many pixels and thus reduce the SNR, or if the pixel is too big the night sky will contribute additional noise and also lower the SNR. The image size depends on the atmospheric seeing, therefore, the selection of pixel size depends on the seeing expected at a site. The ideal way to measure seeing at the ETS would be to use an automated version of what was done in this report. The microprocessor based PVDS system would be ideal for this purpose and could provide a short exposure measure of seeing. Using a CCD camera mounted on the cassegrain position of the 31" ETS telescope would provide even more detail of the image intensity distribution. Binary stars could be viewed to eliminate some observing uncertainties and data could be collected on a regular basis.

ACKNOWLEDGMENTS

I would like to acknowledge that R. Martinson designed the digitizer and MODCOMP interface, and that M. MacDonald and L. Eaton installed and tested the equipment at the ETS. E. Rork operated the telescope console, E. Freedman the MODCOMP, and D. Kostishack and N. Pong the CCD camera.

The typing of this report was carefully done by G. Jodice and the figures were pasted-up by J. Surabian.

APPENDIX A

```
10    DIM D$(500)[362]                          !   "MOD-HP"
20    CREATE "T11F01",1,10000
30    ASSIGN #1 TO "T11F01"
40    RESET 10
50    WRITE IO 10,5;1
60    WAIT WRITE 10,4;64
70    WAIT WRITE 10,4;203
80    WAIT WRITE 10,4;32+7
90    READ IO 10,4;R4
100   WRITE IO 10,5;0
110   WAIT READ 10,4;A                          !READY
120   WRITE IO 10,7;0                           !TRIGGER
130   !
140   !           SET UP THE 98036A TO INTERRUPT ON INPUT DATA
150   !
160  WRITE IO 10,5;128+4
170   F=IOFLAG(10)
180   S=IOSTATUS(10)
190   PRINTER IS 16
200   PRINT "I/O FLAG   1 ",F,"I/O STATUS   1 ",S
210   READ IO 10,5;R5
220   READ IO 10,6;R6
230   STATUS 10;V
240   PRINT "R4     0 ",R4,"R5   146 ",R5,"R6   248 ",R6,"V    402 ",V
250   I=0                                       !INDEX FOR WORDS COMING OVER
260   BEEP
270   BEEP
280   TOPEN 10,2 GOSUB Getinput
290 Loop:                                       ! WAIT FOR DATA FROM MODCOMP
300   ON KBD 1 GOTO 310
310   K$=KBD$
320   Ex=POS(K$,CHR$(255)&CHR$(21))
330   IF Ex<>0 THEN 440
340   GOTO Loop
350 Getinput:                                   ! GET INPUT FROM INTERFACE
360   I=I+1
370   IF I>500 THEN Loop
380   D$(I)=TBUF$
390   IF POS(D$(I),CHR$(5)) THEN OUTPUT 10;CHR$(6)
400   PRINTER IS 16
410   PRINT I
420   WAIT 900
430   RETURN
440   FOR I=1 TO 500
450   PRINT #1;I,D$(I)
460   NEXT I
470   END
```

"MOD-HP"

APPENDIX A

```
10    FOR W=10 TO 50                                  ! "READ"
20     DIM D$(200)[320],P(321),O(200),F(1024)
30     X$=VAL$(W)
40     W1$="T11F"&X$&":F8"
50     W2$="T11D"&X$&":T15"
60     ASSIGN #1 TO W1$
70     ON END #1 GOTO 680
80     St=0
90     D=0
100    FOR I=1 TO 200                        !  READ STRING FROM TAPE (I)
110    READ #1;I,D$(I)
120    D$(I)=D$(I)[1,319]&CHR$(13)
130    PRINTER IS 16
140    FOR J=1 TO 200                        !  BREAK STRING INTO VARIABLES (J)
150    IF J>1 THEN 290
160    P(1)=POS(D$(I),CHR$(13))
170    Lf=POS(D$(I)[1,P(1)],CHR$(10))
180    L=LEN(D$(I)[1,P(1)])
190    IF Lf<>0 THEN 240
200    IF L<2 THEN 280
210    O(1)=VAL(D$(I)[1,P(1)])
220    D=1
230    GOTO 290
240    IF L<3 THEN 280
250    O(1)=VAL(D$(I)[2,P(1)])
260    D=1
270    GOTO 290
280    O(1)=-1
290    J1=J+1
300    P(J1)=POS(D$(I)[P(J)+1],CHR$(13))
310    IF P(J1)=0 THEN 480
320    P(J1)=P(J1)+P(J)
330    L=LEN(D$(I)[P(J)+1,P(J1)])
340    IF L<4 THEN 460
350    Lf=POS(D$(I),CHR$(10))
360    IF Lf<>0 THEN 390
370    G=1
380    GOTO 430
390    G=2
400    D$(I)[P(J)+G,P(J1)]=TRIM$(D$(I)[P(J)+G,P(J1)])
```

"READ"

```
410     L=LEN(D$(I)[P(J)+G,P(J1)])
420     IF L<6 THEN 460
430     O(J1)=VAL(D$(I)[P(J)+G,P(J1)])
440     D=D+1
450     GOTO 470
460     O(J1)=-1
470     GOTO 500
480     S=D
490     GOTO 510
500     NEXT J                               !  NEXT J
510     Ss=0
520     Cs=St+1-Ss
530     Cf=St+S
540     D=0
550     IF (O(1)=-1) AND (S=0) THEN 670
560     FOR K=Cs TO Cf                       !  PACK VARIABLES FOR OUTPUT (K)
570     L=K-St+Ss
580     IF O(L)=-1 THEN 600
590     GOTO 640
600     L=L+1
610     Cf=Cf-1
620     Ss=Ss+1
630     GOTO 580
640     F(K)=O(L)
650     NEXT K                               !  NEXT K
660     St=St+S
670     NEXT I                               !  NEXT I
680     FOR M=1 TO 32                        !  OUTPUT DATA (M)
690     FOR N=M TO 1023+M STEP 32
700     IMAGE #,4D
710     PRINT USING 700;F(N)
720     NEXT N
730     PRINT LIN(1)
740     NEXT M                               !  NEXT M
750     ON END #2 GOTO 790
760     CREATE W2$,1,9000
770     ASSIGN #2 TO W2$
780     PRINT #2;F(*)
790     NEXT W
800     END
```

"READ" (Cont.)

```
10    FOR I=10 TO 50                 ! "COPY"
20    I$=VAL$(I)                     ! FRAME NUMBER
30    T$="T11D"
40    P1$=":T15"                     ! TAPE DRIVE
50    P2$=":F"                       ! DISC
60    F1$=T$&I$&P1$
70    F2$=T$&I$&P2$
80    PRINT F1$,F2$
90    COPY F1$ TO F2$
100   NEXT I
110   END
```

"COPY"

APPENDIX B

```
10    PRINT "FRAME"," "," ","POSITION"         ! "MAXAMP"
20    FOR I=10 TO 50
30    DIM F(1024)
40    I$=VAL$(I)
50    V$="T11V"&I$&":F"
60    ASSIGN #1 TO V$
70    ON END #1 GOTO 100
80    READ #1;F(*)
90    Max=0
100   FOR M=1 TO 32                         !  OUTPUT DATA (M)
110   FOR N=M TO 1023+M STEP 32
120   IF F(N)>Max THEN 140
130   GOTO 160
140   Max=F(N)
150   Nax=N
160   NEXT N
170   NEXT M                                !  NEXT M
180   PRINT V$,"MAXIMUM AMPLITUDE",Max,Nax
190   PRINT LIN(1)
200   NEXT I
210   END
```

"MAXAMP"

```
10   PRINTER IS 16                           ! "FREDIS"
20   PRINT PAGE;"   This program allows the user to enter a frame of data and ha
ve a"
30   PRINT " frequency distribution computed and drawn."
40   PRINT LIN(1);"   After the distribution, a beep will sound.  The chart will
"
50   PRINT "remain on the screen and the program will halt until you press CONT
."
60   PRINT "This will give you time to digest the information on the screen."
70   PRINT LIN(1);"   If you want the output of this program dumped from the CRT
"
80   PRINT "to the internal thermal printer, then answer Y to the question below
."
90   PRINT "If you don't want hardcopy answer N. Then press CONT."
100  INPUT "Do you want hardcopy (Y/N)?",A$
110  IF UPC$(A$)="Y" THEN Yhard
120  IF UPC$(A$)="N" THEN Nhard
130  BEEP
140  GOTO 100
150 Yhard:  Hardcopy=1
160  GOTO 180
170 Nhard:  Hardcopy=0
180  N=224
190  CALL Driver(N,Hardcopy)
200  END
210  SUB Driver(N,Hardcopy)
220  RANDOMIZE
230  DIM A(N),L$(N),Units$[30],V(1024)
```

"FREDIS"

APPENDIX B

```
240   INPUT "Which frame 01 to 50?",Fr$
250   V$="T11V"&Fr$&":F"
260   ASSIGN #1 TO V$
270   READ #1;V(*)
280   Max=V(1)
290   FOR J=1 TO 1024
300   Max=MAX(Max,V(J))
310   NEXT J
320   MAT A=ZER
330   High=0
340   Lhigh=4096
350   FOR K=1 TO 1024
360   IF (V(K)>High) AND (V(K)<Lhigh) THEN 380
370   GOTO 390
380   High=V(K)
390   NEXT K
400   FOR J1=1 TO 1024
410   IF V(J1)=High THEN 430
420   GOTO 440
430   A(High)=A(High)+1
440   NEXT J1
450   IF High=0 THEN 490
460   Lhigh=High
470   High=0
480   GOTO 350
490   PRINTER IS 0
500   PRINT
510   PRINT V$
520   PRINT "MAX AMP"
530   PRINT Max
540   PRINTER IS 16
550   FOR I=20 TO Max STEP 20                         ! ENTER THE TITLES
560   L$(I)=VAL$(I)
570   NEXT I
580   Units$="Number of Pixels"
590   Title$="Amplitudes"
600    N=Max
610   CALL Bar(A(*),L$(*),N,Units$,Title$)
620   BEEP
630   PAUSE
640   IF Hardcopy=1 THEN DUMP GRAPHICS
650   EXIT GRAPHICS
660   SUBEXIT
670   SUB Bar(A(*),L$(*),N,Units$,Title$)
680   PLOTTER IS "GRAPHICS"
690   GCLEAR
700   GRAPHICS
710   PEN 1
720   Sum=0
```

"FREDIS" (Cont.)

```
730  Max=A(1)
740  FOR I=1 TO N
750  Sum=Sum+A(I)
760  Max=MAX(Max,A(I))
770  NEXT I
780  Ly=LGT(Max)
790  SETGU
800  LOCATE 15,120,40,95                    ! Set screen boundaries and scale
810  CLIP 0,123,40,100
820  MOVE 61.5,97
830  LORG 5
840  LABEL USING 850;Title$
850  IMAGE #,K
860  SCALE 0,N+.5,0,Max+Max/10
870  Xtic=0                                 ! No tic marks on horizontal axis
880  Testytic=FRACT(Ly)+(Ly<0)
890  Ytic=10^(INT(Ly)-1)*(1+1.5*((Testytic>.39794) AND (Testytic<.69897))+4*((Te
stytic>=.69897) AND (Testytic<=.87506))+6.5*(Testytic>.87506))
900                                         ! Compute the vertical tic marks
910  CALL Laxes(Xtic,Ytic,0,0,1,1,2,0,N+.5,0,Max+Max/10)
920  LORG 4
930  FIXED 1
940  FOR I=0 TO N
950  MOVE I-.5,0
960  IPLOT 0,A(I),-1                       ! Draw the bar for the ith data item
970  IPLOT 1,0
980  IPLOT 0,-A(I)
990  MOVE I,A(I)
1000 NEXT I
1010 DEG
1020 IMAGE K
1030 LDIR 90                                ! Rotate the label 90 degrees
1040 SETGU
1050 LORG 5
1060 MOVE 5,70
1070 LABEL USING 1020;Units$                ! Write the display units being
1080                                        ! used along the vertical axis
1090 CLIP 0,123,0,100
1100 SETUU
1110 FOR I=1 TO N
```

"FREDIS" (Cont.)

APPENDIX B

```
1120 MOVE I,-Max/20
1130 LORG 8
1140 PEN 1
1150 LDIR 90                              ! Rotate the labels 90 degrees
1160 LABEL USING 1020;L$(I)
1170 NEXT I
1180 BEEP
1190 SUBEXIT
1200 SUB Laxes(Xtic,Ytic,Xorg,Yorg,Xmaj,Ymaj,Minticsize,Xmin,Xmax,Ymin,Ymax)
1210 IF (Xmin>=Xmax) OR (Ymin>=Ymax) THEN SUBEXIT
1220 Xfudge=.02*(Xmax-Xmin)
1230 Yfudge=.02*(Ymax-Ymin)
1240 AXES Xtic,Ytic,Xorg,Yorg,Xmaj,Ymaj,Minticsize
1250 DEG
1260 IF NOT Xtic THEN Labely
1270 Labelx:IF SGN(Xtic)=-1 THEN Parx
1280 LDIR 90
1290 LORG 8
1300 GOTO 1330
1310 Parx: LDIR 0
1320 LORG 6
1330 FOR I=Xorg TO Xmax STEP ABS(Xtic)
1340 MOVE I,Yorg-Yfudge
1350 LABEL USING 1360;I
1360 IMAGE #,K
1370 NEXT I
1380 Labely: IF NOT Ytic THEN SUBEXIT
1390 IF SGN(Ytic)=-1 THEN Pary
1400 LDIR 0
1410 LORG 8
1420 GOTO 1450
1430 Pary: LDIR -90
1440 LORG 6
1450 FOR I=Yorg TO Ymax STEP ABS(Ytic)
1460 MOVE Xorg-Xfudge,I
1470 LABEL USING 1360;I
1480 NEXT I
1490 SUBEXIT
```

"FREDIS" (Cont.)

APPENDIX B

```
10     DIM F(1024)                              ! "PEAKS"
20     F$="T11V22:F"
30     L=19
40     PRINTER IS 0
50     PRINT F$,"PEAKS ABOVE",L
60     PRINT
70     PRINT "ROW","COLUMN","POSITION","AMPLITUDE"
80     PRINTER IS 16
90     ASSIGN #1 TO F$
100    ON END #1 GOTO 120
110    READ #1;F(*)
120    FOR M=1 TO 32                           !  OUTPUT DATA (M)
130    C=0
140    FOR N=M TO 1023+M STEP 32
150    C=C+1
160    IF F(N)>L THEN 200
170    IMAGE #,4D," "
180    PRINT USING 170;F(N)
190    GOTO 250
200    IMAGE #,4D,"*"
210    PRINT USING 200;F(N)
220    PRINTER IS 0
230    PRINT M,C,N,F(N)
240    PRINTER IS 16
250    NEXT N
260    PRINT LIN(1)
270    NEXT M                                  !  NEXT M
280    PRINTER IS 0
290    PRINT LIN(3)
300    END
```

"PEAKS"

APPENDIX B

```
10    DIM F(1024)                                    ! "DATAST"
20    INPUT "AMPLITUDES HIGHER THEN",L
30    FOR J=10 TO 50
40    PRINT LIN(3)
50    PRINT "FRAME NUMBER",J
60    PRINT LIN(3)
70    S$=VAL$(J)
80    ASSIGN #1 TO "T11V"&S$&":F"
90    ON END #1 GOTO 110
100   READ #1;F(*)
110   FOR M=1 TO 32                                 !  OUTPUT DATA (M)
120   FOR N=M TO 1023+M STEP 32
130   IF F(N)>L THEN 170
140   IMAGE #,4D," "
150   PRINT USING 140;F(N)
160   GOTO 190
170   IMAGE #,4D,"*"
180   PRINT USING 170;F(N)
190   NEXT N
200   PRINT LIN(1)
210   NEXT M                                        !  NEXT M
220   NEXT J
230   END
```

"DATAST"

APPENDIX B

```
10      INPUT "LEVEL",L                              ! "FRAME"
20      FOR I=10 TO 50
30      DIM F(1024)
40      I$=VAL$(I)
50      V$="T11V"&I$&":F"
60      ASSIGN #1 TO V$                              ! DATA FROM DISC
70      ON END #1 GOTO 90
80      READ #1;F(*)
90      GRAPHICS
100     LINE TYPE 1
110     SCALE 0,12,0,15
120     FOR M=15 TO 25                               ! LABEL AMPLITUDES
130     C=0
140     FOR N=M TO 1023+M STEP 32
150     C=C+1
160     IF F(N)<L THEN 200
170     MOVE M-15,C
180     LABEL F(N)
190     IF C=13 THEN 210
200     NEXT N
210     NEXT M
220     WAIT 3000
230     GCLEAR
240     SCALE 0,13,0,230
250     FOR M=19 TO 22                               ! PLOT COLUMNS
260     WAIT 200
270     C=0
280     GCLEAR
290     MOVE 0,L                                     ! PLOT LEVEL
300     LINE TYPE 4
310     DRAW 13,L
```

"FRAME"

APPENDIX B

```
320   LINE TYPE 1
330   MOVE 1,150
340   LABEL "COLUMN"
350   MOVE 0,0
360   FOR N=M TO 1023+M STEP 32
370   C=C+1
380   PLOT C-1,F(N)
390   PLOT C,F(N)
400   NEXT N
410   WAIT 500
420   MOVE 0,0
430   NEXT M
440   GCLEAR                              ! PLOT ROWS
450   MOVE 0,0
460   FOR N1=239 TO 335 STEP 32           ! PLOT LEVEL
470   MOVE 0,L
480   LINE TYPE 6
490   DRAW 13,L
500   LINE TYPE 1
510   MOVE 1,150
520   LABEL "ROW"
530   MOVE 0,0
540   FOR M=1 TO 13
550   N=N1+M
560   PLOT M-1,F(N)
570   PLOT M,F(N)
580   NEXT M
590   MOVE 0,0
600   WAIT 500
610   GCLEAR
620   NEXT N1
630   NEXT I
640   END
```

"FRAME" (Cont.)

APPENDIX C

5	7	0	7	14
16	24	19	16	16
9	25	48	16	16
12	127	115	7	7
0	0	13	7	6
0	15	2	7	3

FRAME 1

1	8	15	0	3
1	16	16	12	3
0	20	33	28	7
12	79	156	16	15
0	5	16	12	0
12	7	0	0	0

FRAME 2

7	8	12	7	6
7	14	47	16	16
0	28	35	20	8
0	56	158	23	28
0	8	19	7	0
7	4	5	16	4

FRAME 3

5	16	6	7	1
7	16	15	16	3
0	32	48	15	15
7	120	160	12	6
4	7	16	20	1
3	32	8	3	1

FRAME 4

0	0	3	15	7
15	20	16	8	1
7	24	38	16	7
0	127	121	16	12
0	11	22	16	15
0	4	13	4	0

FRAME 5

11	0	0	12	0
7	16	28	0	12
0	31	38	13	8
0	159	125	16	8
7	16	28	14	4
1	7	1	4	12

FRAME 6

SATELLITE IMAGE FRAMES 1-6

APPENDIX C

0	1	6	7	7
16	16	13	4	6
12	31	32	23	16
6	172	120	3	4
0	12	31	3	7
20	0	0	0	0

FRAME 7

12	16	12	14	0
16	8	16	16	12
0	24	31	7	15
0	112	149	16	8
7	0	25	3	4
4	0	6	4	3

FRAME 8

1	3	15	7	15
0	14	24	14	12
1	24	31	7	0
12	156	111	16	12
0	15	28	12	7
0	7	7	14	7

FRAME 9

6	4	16	4	7
4	15	16	15	8
4	32	28	26	7
8	185	96	14	0
0	12	12	6	4
1	8	3	0	4

FRAME 10

1	12	14	3	4
11	15	7	12	0
0	32	40	18	1
0	182	112	17	7
6	15	19	0	8
16	1	0	1	7

FRAME 11

24	7	1	8	12
0	14	16	7	15
0	28	24	24	12
7	163	95	4	0
7	36	31	4	12
11	2	0	0	7

FRAME 12

SATELLITE IMAGE FRAMES 7-12

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A satellite has been observed through an optical telescope with a CCD camera, the electrical signal stored, and later analyzed with the aid of a digital computer. The unresolved satellite image is contained in 3 to 7 picture elements in fifty contiguous data frames. This allows a better understanding of the physical characteristics of the satellite image as viewed through the atmosphere by an electro-optical detector.

This paper describes the data processing programs used to analyze the data, the analysis results, and implications for signal processing design.

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